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EP 0354045 A US 5394453 A US 5263075 A
US 5007072 A

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INT CL^6 G01N 23/20 23/201 23/207, G01V 5/00
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(54) **Detecting crystalline material using X-ray diffraction**

(57) Apparatus for detecting crystalline and polycrystalline materials such as explosives in luggage in a monitoring zone uses collimators 8 situated on the other side of the monitoring zone from an X-ray source 1 to detect at least one diffracted X-ray beam fan 6 from an area 5 within the monitoring zone. The output window 18 of each collimator 8 views a particular preselected area 5 of the object 4 to be examined. The collimators 8 preferably view a preselectable number of diffracted planar fan beams 6 of which the incidence is symmetrical about the axis of the source X-ray beam in windows 18 which are parallel to each other, so that detectors 9 situated beyond the windows detect sensitive material in the volume of an object which is within the area covered by the source X-ray fan beam.

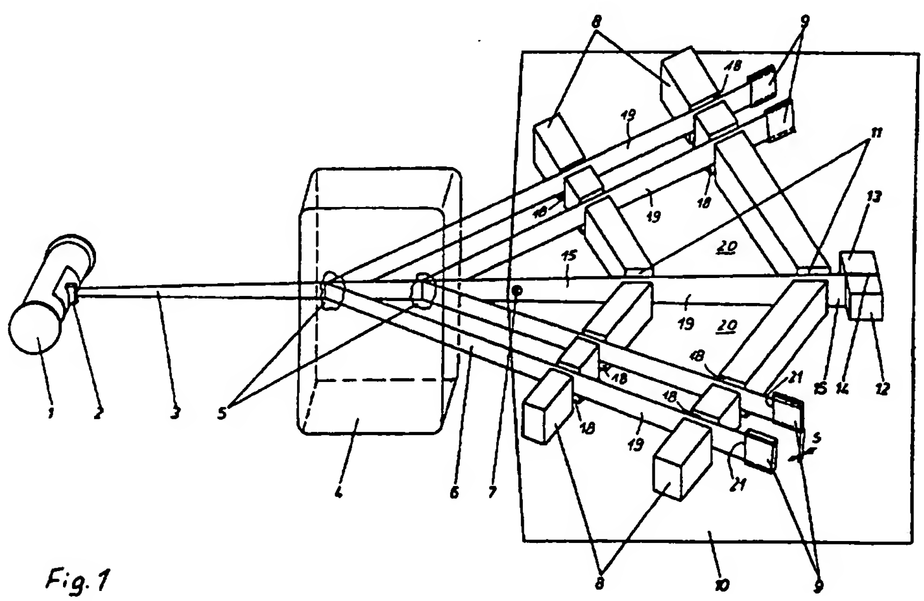

Fig. 1

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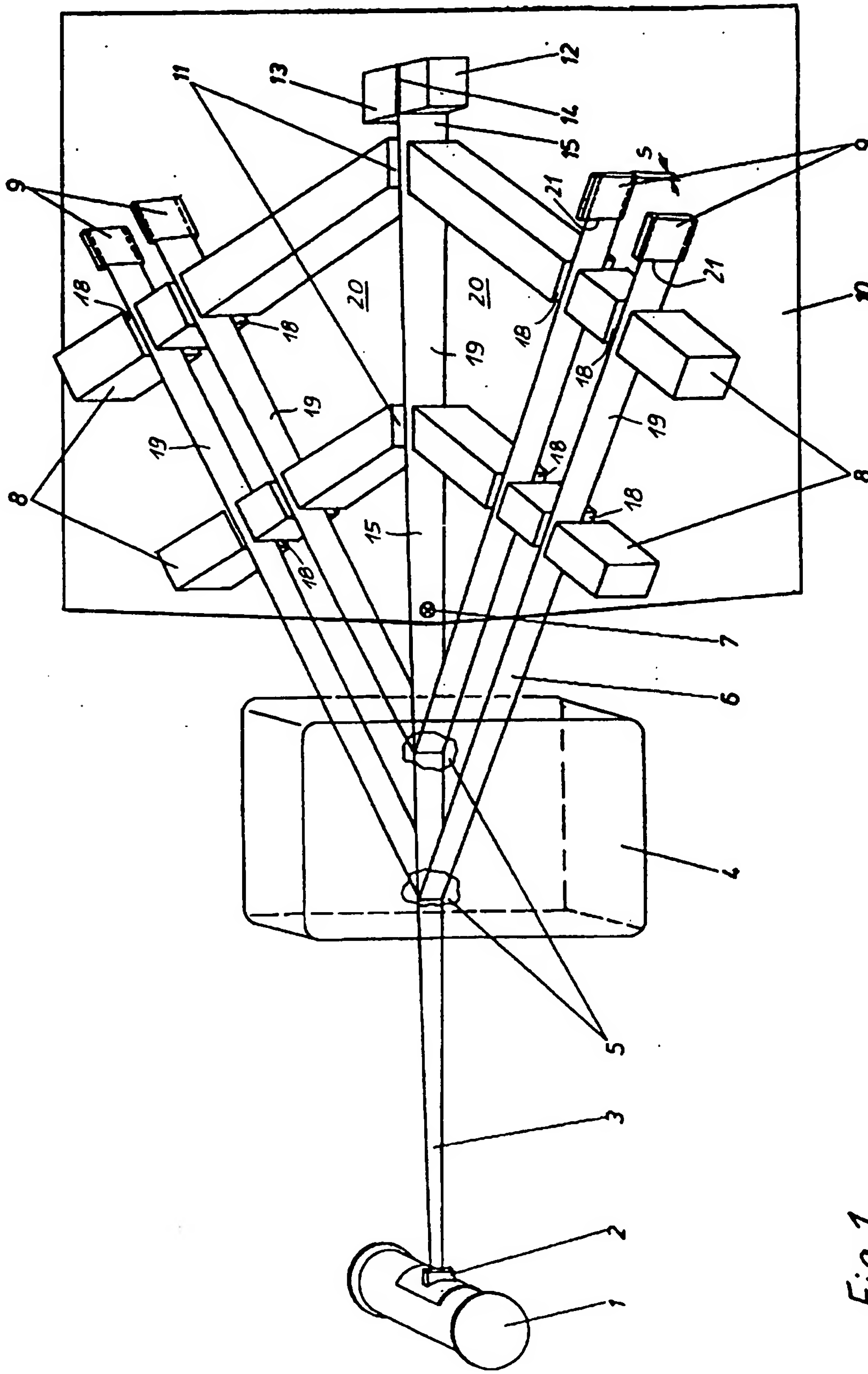

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Fig. 1

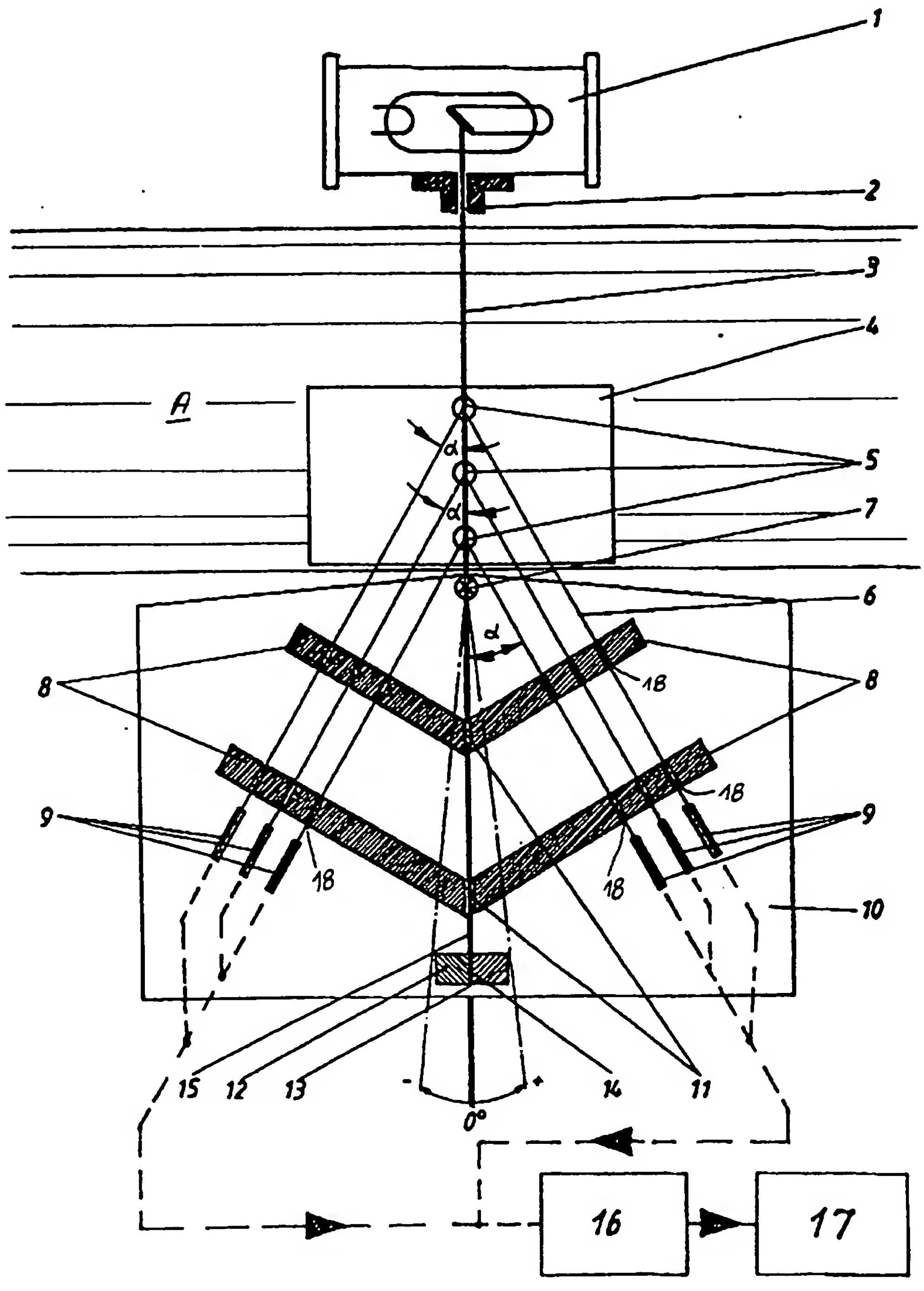

Fig.2

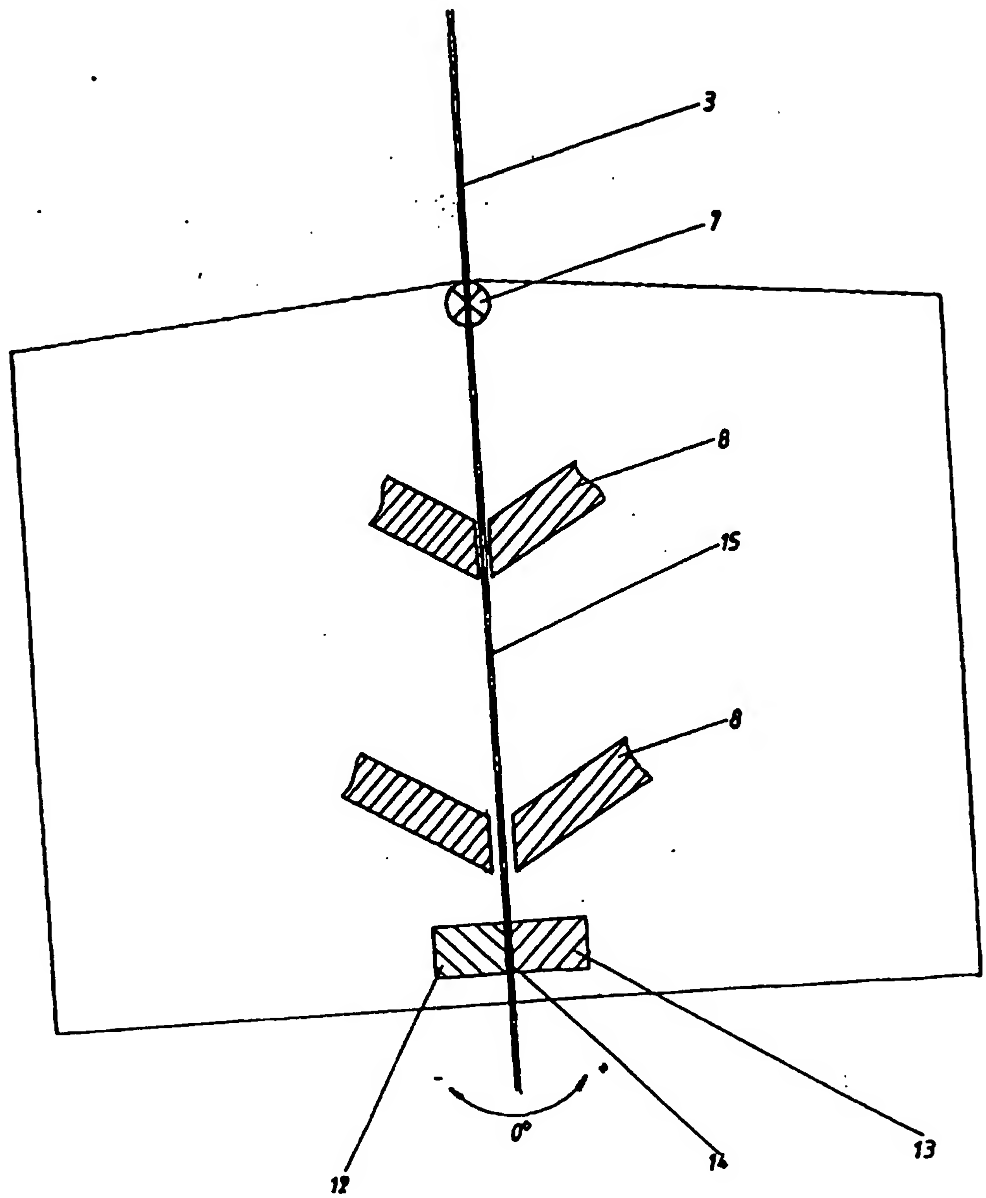

Fig. 3

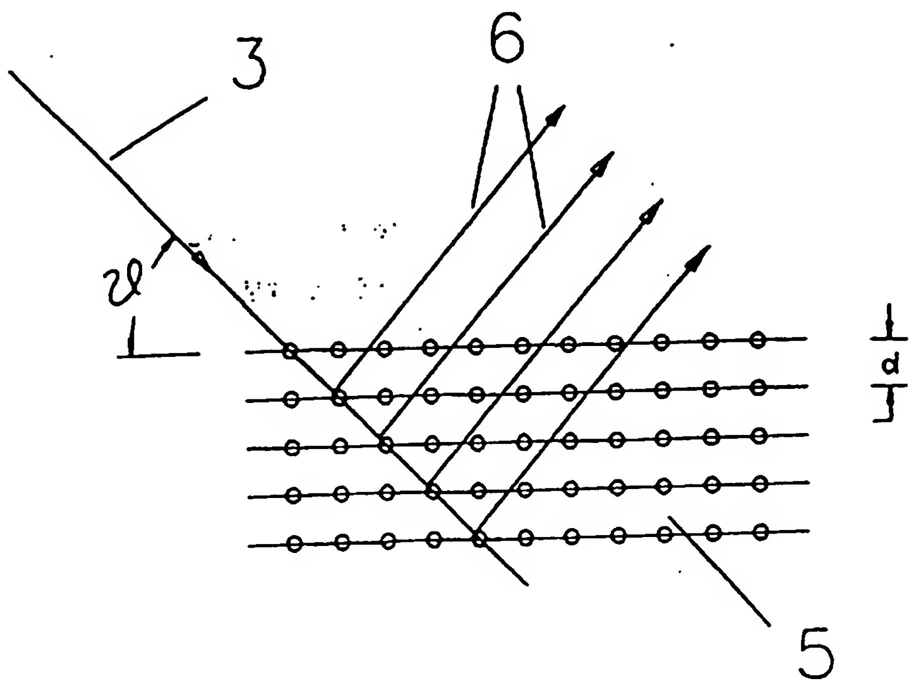

Fig. 4

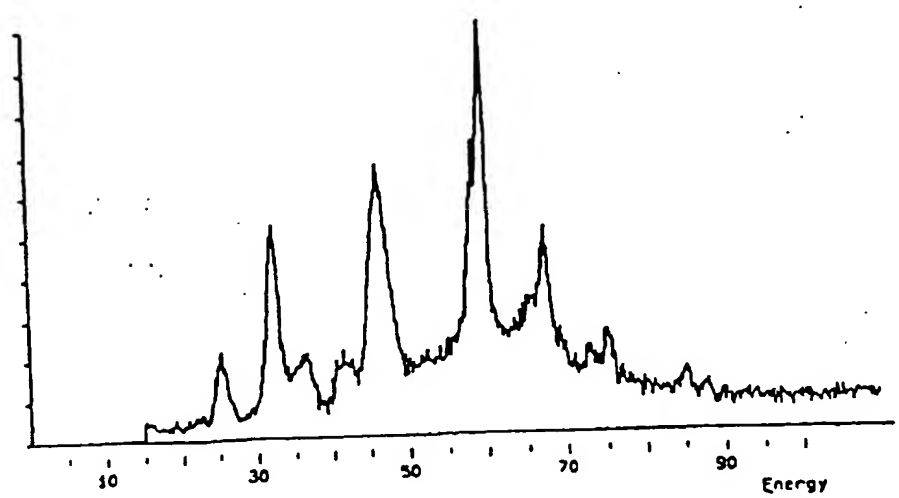

Fig. 5

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TITLE

Method and Apparatus for Detecting Crystalline and Polycrystalline substances.

This invention relates to a method and apparatus for detecting crystalline and polycrystalline substances in a monitoring area.

To ensure the safety of air transport baggage has to be monitored by complex technical means. In this connection the detection of bombs or plastic explosives in baggage is particularly important. The false detection rate of monitoring and detection devices must be kept within reasonable limits and a high probability of detection accompanying a high rate of throughput must be ensured. At the same time such systems must be of robust construction and readily available. Methods of analysis customary in laboratories are only applicable commercially within limits. The requirements may be met, for example, by the use of multi-stage systems.

In principle, given a suitable choice of beam geometry, the physical effect of the refraction of X-rays in the lattice planes of crystalline and polycrystalline materials, which has already been known for many years and which is used for example in X-ray diffractometry in

order to identify and classify materials, can be employed not only on surfaces but also in the transmission process for the purpose of obtaining information on material within bulky three-dimensional objects to be examined, such as air passengers' baggage.

In the simplest kind of case an object is penetrated by an X-ray beam of narrow cross section. If the object consists of materials with a crystalline or polycrystalline lattice structure, individual areas of this structure cause diffraction. In general the diffracted radiation will be caused to cancel by destructive interference. Cases nevertheless occur in which the energy level is amplified.

This will occur whenever a wave length λ is associated with a certain angle ϑ and a constructive interference occurs with a distance d of the crystal planes which is specific to the material. In the known Bragg interference condition the relationships between λ, ϑ and the lattice distance d are summarised as follows:

$$2\,d \times \sin\vartheta = n \times \lambda$$

As may be seen from this equation, the effect can be used in various ways. If a polycrystalline material is subjected to a beam from a polychromatic x-ray apparatus, different maximum energy magnitudes occur for instance, with an angle ϑ which may be regarded as fixed. These

maximum magnitudes are characteristic of the lattice distances in the material being examined. Tests have shown that explosive substances, owing to their polycrystalline structure, will produce energy spectrums of this kind. This method is thus fundamentally suitable for the detection of explosives. A material which it is desired to detect is recognised by a comparison between the spectrum found in the catalogue of relevant spectra filed in the data storage. Methods of this kind are known, for example in X-ray diffractometry of IR spectroscopy and in gas chromatography and are not described here in detail.

In a system known from EP-0209 952 A2 radiation from different angles consisting of dispersion and the energies corresponding to the latter are combined to form groups and then evaluated. In this arrangement cylinder collimators in front of and behind the object to be monitored lead to circular or annular representations and to the relevant detector geometry. For the examination of the regions of the volume which are situated along the pencil beam of X-rays directed into the object, that is deep inside the object, the latter has to be displaced longitudinally to the incident X-ray and the entire apparatus is subjected to a lateral movement in relation to the object. This process calls for a large number of successive measuring

operations, since with each of these it is only possible to examine one single point on the cross-sectional plane along the beam of the X-rays. In this punctiform detection process each detector has to detect the scatter radiation in a number of angular positions and from displacement positions, involving considerable time and calculation.

It is an object of this invention to improve the known methods to provide simplification and a more cost effective solution, enabling all areas throughout the volume of an object to be examined simultaneously.

According to this invention there is provided a method for detecting and/or examination of crystalline and polycrystalline materials in a zone which is irradiated by a beam emanating from an X-ray source through a screen or baffle and having polychromatic energy distribution, the energy spectra of diffracted X-ray radiation from separate areas within the volume of the material along the irradiated cross-section being detected by means of collimators positioned outside the zone and being converted in a data processing device into useful signals, wherein collimators are positioned on the side of the zone opposite the X-ray source, said collimators screening out at least one diffracted planar beam fan from the zone and that each output window of the

collimators detects one preselected zone within the material being examined.

According to this invention there is also provided apparatus for carrying out the method, wherein a monitoring zone for crystalline and polycrystalline materials is provided which is situated between an X-ray source and collimators, a source of X-rays emerging from a screen or baffle and having a polychromatic energy distribution along a zone in the volume of material which is to be examined undergoes diffraction of the said X-ray beam and the energy spectra of the diffracted beam being detected in detectors and converted in a data processing device into useful signals, wherein

(a) the collimators are arranged symmetrically about the axis of the source X-ray beam in a plane perpendicular to a planar fan beam of the X-ray source,

(b) the collimators are positioned in succession to one another in one or in a number of rows,

(c) the collimators have output windows parallel to one another,

(d) the output windows are in each case positioned at a fixed angle α with respect to the axis of the source X-ray beam,

(e) the detectors by which the diffracted X-rays are

detected are positioned on the respective output windows of the rear collimators in the plane of the relevant collimated fan beam.

The invention is based on the realisation that circular collimation equipment is replaced by a linear type and that noticeable improvements are thus obtained, due to the simultaneous examination of all elements in the volume of the object along the incident X-ray. The simplification is mainly due to the fact that the collimators installed beyond the monitoring zone blank out at least one diffracted plane beam fan from the relevant monitoring zone and that each output window of a collimator detects one particular predetermined zone of the cross-sectional plane of the material to be examined.

The method and apparatus of this invention enables all predetermined zones in the cross-sectional plane of the object to be detected simultaneously, so that complete cross sections of the object can be monitored in rapid succession. The process and the apparatus render the detection highly accurate, because the collimation and detection unit can be automatically aligned with the focus of the X-ray source and adjusted. The collimator and detection unit can be positioned in different planes along the incident X-ray, preferably in a vertical and in a horizontal plane, so that by multiple measurement of

the monitoring zone more rapid detection of the material to be examined will be possible.

The method and the apparatus offer the advantage of enabling silicon-photo-diodes to be used as semi-conductor detectors and is thus simpler and more economical than the use, generally required for this technique, of cooled germanium detectors, for example.

The invention will be explained in more detail by reference to an embodiment shown by way of example and schematically in the accompanying drawings, wherein:-

Figure 1 shows a three-dimensional illustration of the collimation and detection of diffracted plane fan beams along an X-ray penetrating the object under examination,

Figure 2 shows a plan view of the apparatus for collimation and detection,

Figure 3 shows a diagram of a collimation device, with means for alignment and adjustment,

Figure 4 shows the physical effect of diffraction of X-rays in lattice planes of crystalline and polycrystalline materials, and

Figure 5 shows energy spectra for displaying the polycrystalline structure of explosive materials.

Figures 1, 2 and 3 show an X-ray source 1 (X-ray

generator) from which an X-ray beam of less than 100 KeV is collimated using, as example, a diaphragm or lens or screen 2, in such a way that a fan beam 3 of narrow cross section with a thickness of less than 1 mm and a width of about 10 mm is produced. The central X-ray beam 3 emerging from the screen 2 has a polychromatic energy distribution and in a monitoring zone A for detecting crystalline and polycrystalline materials penetrates an object 4 at a certain defined point. In this process diffraction centres 5 are created along the X-ray beam. On that side of the monitoring zone A which is opposite to the X-ray source 2 slotted collimators 8 are positioned symmetrically around the axis of the central X-ray 3,15 in a plane 20 perpendicular to a plane 19 of the fan beam of the X-rays. These collimators 8 can be arranged in one row or in a number of successive rows, in which case the collimators 8 contain output windows 18 parallel to one another and each positioned at a fixed angle α in relation to the axis of the central X-ray 15. On the respective output windows 18 of the rear collimators 8 the detectors 9 detecting the X-radiation 6 diffracted by the diffraction centres are provided in the plane 19 of the fan beam 6 collimated through the said windows.

The detectors 9 detect the energy spectra of the

diffracted radiation 6 and transmit them to a data processing device 16 in which the data is converted into useful signals which can be displayed in a subsequent terminal unit 17. In addition, the examination can be automatically evaluated by comparing the measured spectra with known explosive material spectra stored in the system.

As a departure from the system shown in Figures 1 and 2, the output windows 18 can be arranged parallel to one another on the collimators 8, in each case at a constant angle α within the range 2.4^{o} and 3^{o}, in relation to the central X-ray axis 15, so that the entire cross-sectional area of the central fan beam 3 delimited by the object 4 to be examined can be investigated simultaneously.

The output windows 18 of the collimators 8 have a width ≥ 1 mm, preferably between 0.3 and 0.5 mm, and a height of about 10 mm. To the output windows 18 are attached, for example, silicon photo-detectors 9 with an end surface area of between 1 and 5 mm^2, these serving to intercept the diffracted collimated fan beam 6. Due to the high energy resolution which can be obtained the thickness of the collimated pencil beam preferably ranges from 0.3 to 0.5 mm^2 at the detector and it is possible to use a semi-conductor silicon photo-diode 9. Silicon photo-diodes are generally used in X-ray techniques as

detectors for α and β radiation. This is due in particular to the fact that the radiation-sensitive charge zone inside the semi-conductor material has a thickness of about 0.3 mm. In accordance with the atomic number silicon is capable of completely absorbing α and β radiation within this material thickness range. This is far less the case with high-energy γ radiation between 10 and 100 KeV. For this reason the silicon photo-diode 9 is used in such a way that the incidence of the collimated fan beam 6 takes place parallel to or along the semi-conductor-sensitive zone or plane. As the fan beam thickness and sensitive semi-conductor zone are of the same order of magnitude, this leads to no appreciable loss of information. As a further advantage the narrow detector zone provides a supplementary collimation in itself, because radiation passing the side of the detection plane must naturally emanate from a solid angle which does not have to be taken into consideration.

The known drawbacks of silicon material, result from the low rate of light absorption in the energy range above 50 keV, which can be counteracted by connecting a number of detectors in parallel. As the energy range below 20 keV is of no interest in obtaining diffraction spectra, the Compton edge has no adverse effect on the

evaluation.

The monitoring zones 5 formed in the depth of the object, along the incident X-ray fan beam 3, can also be examined by the aforementioned method in further planes, for example in an oblique or vertical plane, in which case the screen 2 at the X-ray source 1 must be supplemented, in a manner not shown, by a further vertical or oblique screen and the collimation and detection apparatus by further collimators and detectors in these planes.

The collimation and detection apparatus offers the further advantage of a compact construction enabling the entire system to be set-up and adjusted simply. It is obvious that the adjustment has a decisive effect on the sensitivity and thus on the recognisability of the material and on the detection probability. One single adjustment of an apparatus of this kind, for example on installation, is not sufficient. On the contrary, it has to be assumed that automatic readjustment will be required at regular intervals, for example prior to every measurement of an object to be examined.

For these reasons the apparatus described is supplemented by a suitable adjustment device, so that the collimator and the detector arrangement 8,9 are mounted on one common support unit 10 and contain, for the

automatic alignment and adjustment of the collimators 8 and detectors 9, a central collimator 11 which can be aligned via a further bearing point 7 to the focus of the X-ray source 1. This central collimator 11 consists of individual detectors 12, 13 situated in opposed pairs on the contact surfaces 14 and unconnected as regards signals.

The automatic adjustment is effected in such a manner that if the detection unit is accurately aligned the central beam 15 emitted by the X-ray source 1 passes through the central collimators 11, while part-signals, preferably equal, are generated in each individual detector 12,13. In the event of an incorrect adjustment the automatic readjustment can be effected via the evaluation of the detected signals and by means of a control device not described in detail. The adjustment of a second plane takes place in the same manner, for example using a second pair of detectors staggered at an angle of 90°.

The individual detectors 12, 13 also termed split detectors, may consist of two scintillation detectors in the case of the adjustment of the apparatus in one plane or of four detectors in the case of the adjustment of the apparatus in a horizontal and a vertical plane, for example.

Figure 4 clarifies the principle of the physical effect of the diffraction, for example in a material penetrated by an X-ray beam of small cross section and having a crystalline or polycrystalline lattice structure. In the example illustrated the X-ray beam 3 penetrates the crystal planes separated from each other by a distance, d, specific to the material, the individual quantities on this structure being diffracted.

Figure 5 illustrates maximum energies obtained by the aforementioned method and produced, for example, by explosive substances being examined due to the polycrystalline structure.

CLAIMS

1. Method for detecting and/or examination of crystalline and polycrystalline materials in a zone which is irradiated by a beam emanating from an X-ray source through a screen or baffle and having polychromatic energy distribution, the energy spectra of diffracted X-ray radiation from separate areas within the volume of the material along the irradiated cross-section being detected by means of collimators positioned outside the zone and being converted in a data processing device into useful signals, wherein collimators are positioned on the side of the zone opposite the X-ray source, said collimators screening out at least one diffracted planar beam fan from the zone and that each output window of the collimators detects one preselected zone within the material being examined.

2. Method in accordance with Claim 1, wherein the collimators screen out a preselected number of diffracted planar fan beams symmetrically from the axis of the X-ray source beam and in a plane perpendicular to the plane of the source beam.

3. Method in accordance with Claim 1 or 2, wherein the

diffracted beams pass through mutually parallel output windows of collimators positioned parallel and successively.

4. Method according to any one of Claims 1 to 3, wherein the diffracted fan beam passes through output windows of collimators positioned in parallel.

5. Method according to any one of Claims 1 to 4, wherein the output windows form X-ray beam fans of small cross section with a thickness not exceeding 1 mm, preferably between 0.3 and 0.5 mm, and with a width not exceeding 10 mm.

6. Method according to any one of Claims 1 to 5, wherein the diffracted planar fan beam passes through the collimators at a preselected fixed angle α within the range 2.4 to 4°, preferably 2.4 to 3°, in relation to the axis of the source beam.

7. Method according to any one of Claims 1 to 6, wherein the fan beams passing through the collimators enter silicon photo-detectors mounted on the output windows of the collimators.

8. Method according to any one of Claims 1 to 7, wherein each fan beam enters the plane of a sensitive semi-conductor layer of a silicon photo-detector.

9. Method according to Claim 7 or 8, wherein each fan beam enters an end surface of a silicon photo-diode having an area between 1 and 5 mm^2 and that the small layer thickness of the semi-conductor zone further collimates the fan beam.

10. Apparatus for carrying out the method according to any one of Claims 1 to 9, wherein a monitoring zone for crystalline and polycrystalline materials is provided which is situated between an X-ray source and collimators, a source of X-rays emerging from a screen or baffle and having a polychromatic energy distribution along a zone in the volume of material which is to be examined undergoes diffraction of the said X-ray beam and the energy spectra of the diffracted beam being detected in detectors and converted in a data processing device into useful signals, wherein

(a) the collimators are arranged symmetrically about the axis of the source X-ray beam in a plane perpendicular to a planar fan beam of the X-ray source,

(b) the collimators are positioned in succession to one another in one or in a number of rows,

(c) the collimators have output windows parallel to one another,

(d) the output windows are in each case positioned at a fixed angle α with respect to the axis of the source X-ray beam,

(e) the detectors by which the diffracted X-rays are detected are positioned on the respective output windows of the rear collimators in the plane of the relevant collimated fan beam.

11. Apparatus for carrying out the method of Claim 10, wherein the fixed angle of inclination α of the output windows of the collimators is within the range 2.4 to 3^{o}.

12. Apparatus for carrying out the method of Claim 10 or 11, wherein the output windows of the collimators have a thickness not exceeding 1 mm and preferably between 0.3 and 0.5 mm and a width not exceeding 10 mm.

13. Apparatus for carrying out the method of any one of Claims 10 to 12, wherein the detector mounted on each output window is a silicon photo-detector having an end surface area of from 1 to 5 mm^2 and serving to receive

the diffracted collimated fan beam.

14. Apparatus for carrying out the method according to any one of Claims 10 to 13, wherein the collimators are mounted on a supporting means and include for the automatic alignment and adjustment of the detectors a central collimator which can be aligned with the focus of the X-ray source.

15. Apparatus for carrying out the method according to any one of Claims 10 to 14, wherein the central collimator for the adjustment and alignment of the collimators and detectors comprises individual diodes situated opposite each other in a pair and of which output signals are unconnected.

16. Method substantially as herein described and exemplified with reference to the drawings.

17. Apparatus for detecting crystalline and polycrystalline substances as described herein and exemplified with reference to the drawings.

The Patent Office

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Application No:	GB 9605913.4	**Examiner:**	David Brunt
Claims searched:	1-17	**Date of search:**	30 May 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): G1A (ADB), H5R (RAL, RAQ, RCD)

Int Cl (Ed.6): G01N (23/20, 23/201, 23/207), G01V (5/00)

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
A	EP 0354045 A2	(ION TRACK) whole document	1,10
A	US 5394453	(HARDING) whole document	1,10
A	US 5263075	(McGANN) whole document	1,10
A	US 5007072	(JENKINS) whole document	1,10

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Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.